REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-04-

0022

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
November 1, 2003	Final Technical	04/01/2000-03/31/2001

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
~~Dynamics and Control of Agile Formations~~	
	5b. GRANT NUMBER
	F49620-00-1-0213
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
Urbashi Mitra **20040130 075**	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Department of Electrical Engineering 756 Dreese Labs, 2015 Neil Ave. The Ohio State University Columbus OH 43210	

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
Air Force Office of Scientific Resesearch (AFOSR) Dr. Jon Sjogren AFOSR/NM, Room 713 4015 Wilson Blvd. Arlington, VA 22203-1954	AFOSR
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

N/A

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT

The Wireless Communications Laboratory (WCL) at Ohio State University has been built up with an RF fading channel emulator, base station mobile units and computational engines, that are integral to the establishment of a state-of-the-art wireless test-bed for Code Division Multiple Access research. These components are being used rigorously to test Code-Division Multiple Access communication. The equipment enhancements have enabled a real-time system, based on "software radio" to replace off-line data manipulation experiments. This next theoretical/experimental stage is critical and progress is being achieved through exploiting very specific wireless characteristics.

15. SUBJECT TERMS
Wireless Network, Radio Frequency Receiver, Channel Emulation, Code-Division Multiple Access

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Urbashi Mitra
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**		3	**19b. TELEPHONE NUMBER** *(include area code)* (614) 292 3902

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Title:
Instrumentation to Support Advanced Research in Wireless CDMA Communications

AFOSR Grant F49620-00-1-0213
Final Report: Nov. 1, 2003

PD/PI: Prof. Urbashi Mitra

Organization:
The Ohio State University
Department of Electrical Engineering
756 Dreese Labs, 2015 Neil Ave.
Columbus OH 43210

TABLE OF CONTENTS

1. OBJECTIVES

We defined and we pursued a novel line of research that lies in a
multidisciplinary intersection of Estimation Theory, Communications Theory,
and Mean-Square optimum linear filtering. Consider an arbitrary input signal
vector space and a given information bearing signal vector to be protected
or recovered in the presence of multiuser or other forms of heavy interference.
Based strictly on statistical conditional optimization principles, we developed
an iterative algorithm that starts from the conventional matched-filter
correlator and generates a sequence of linear filters ("auxiliary-vector"
filters) that converges to the exact MS-optimum solution. At each iteration
step, the filter is given as a direct function of the input autocorrelation
matrix, the signal vector waveform to be protected, and the filter at the
previous iteration. When the autocorrelation matrix is sample-average estimated
from a short data record, this procedure offers the means for effective control
over the filter estimator bias versus (co-)variance trade-off. For a fixed data
record size the filter estimators in this sequence have rapidly decreasing bias
and slowly increasing variance. They outperform other known estimators such as
Sample-Matrix-Inversion (SMI), Diagonal-Loading (DL) SMI, RLS, LMS,
reduced-rank eigenvector decomposition and "multistage" nested Wiener filter.
While all of the above estimators converge to the optimum MMSE/MVDR solution for
infinitely long data record, for any given finite data set there is at least
one AV filter estimator in the sequence that outperforms the SMI, DL-SMI,
RLS, LMS, reduced-rank eigenvector decomposition as well as the multistage
nested Wiener filter.

Finally, we looked at the problem of binary code design. Although this
investigation is at an initial stage, our theoretical developments so far
advanced the prior-state-of-the-art in the context of fundamental binary
code design for code division signal multiplexing. We developed novel,
doubly optimal designs of minimum total-squared-correlation (TSC) and
minimum maximum-squared-correlation (MSC) binary codes and we pursued
theoretical analysis of the codes and application for interference avoidance
at the transmitter-end of a communication link.

2. SUMMARY OF RESEARCH EFFORT

The milestones reached during the duration of this research project

(2 years) are as follows.

(i) We addressed successfully the problem of determining an automated
theoretically derived rule for the selection of the best number of auxiliary
vectors for a given data record of input observations.

(ii) We developed a recursive algorithm for the on-line estimation of the
AV filter and a modified RLS-type algorithm for the estimation of the MMSE/MVDR
filter that are both based on the interference-plus-noise covariance matrix
estimate and we established formally their convergence properties.

(iii) We investigated theoretically the coarse synchronization performance of
blind adaptive linear self-synchronized receivers for asynchronous direct-
sequence spread-spectrum communications under finite data record adaptation.
We derived analytical expressions that approximate the probability of
coarse synchronization error of matched-filter-type (MF) and minimum-variance-
distortionless-response-type (MVDR) receivers based on transformation
noise modeling techniques.

(iv) We studied theoretically the data-record-size requirements of MMSE/MVDR-
type adaptive algorithms to meet a given performance objective in joint
space-time signal detection and direction-of-arrival (DoA) estimation problems
for direct-sequence spread-spectrum systems. We derived closed form expressions
that provide the data record size that is necessary to achieve a given
performance confidence level in a neighborhood of the optimal performance point,
as well as expressions that identify the performance level that can be reached
for a given data record size.

(v) As an application of great importance to AFRL, we addressed the problem of
navigation data demodulation by an adaptive GPS receiver that utilizes a bank
of single-satellite linear-tap-delay filters and employs antenna-array reception.

3. ACCOMPLISHMENTS/NEW FINDINGS

Selecting the most successful (in some appropriate sense) AV filter
estimator in the generated sequence for a given data record was a problem
that had not been addressed so far. We dealt exactly with this problem
and we proposed two data driven selection criteria [1],[2],[3]. The first
criterion is specific to digital communications (binary hypothesis testing)
and maximizes the estimated J-divergence of the AV-filter output
conditional distributions given the transmitted information bit. The
second criterion applies to all filter estimation problems and
minimizes the cross-validated sample average variance of
the AV-filter output.

We observed that the presence of the desired signal during estimation
of the minimum-mean-square-error (MMSE)/minimum-variance-distortionless-
response (MVDR) and auxiliary-vector (AV) filters under limited data
support leads to significant signal-to-interference-plus-noise ratio (SINR)
performance degradation. We quantified this observation in the context
of DS/CDMA communications by deriving close approximations for the mean-
square filter estimation error, the probability density function of the
output SINR and the probability density function of the symbol-error-rate
(SER) of the sample-matrix-inversion (SMI) receiver evaluated using both
desired-signal-present and desired-signal-absent input covariance matrix.
To avoid such performance degradation we proposed a DS/CDMA receiver that
utilizes a simple pilot-assisted algorithm that estimates and then subtracts
the desired signal component from the received signal prior to filter
estimation. Then, to accommodate decision directed operation we developed
two recursive algorithms for the on-line estimation of the AV and MMSE/MVDR
filter and we studied their convergence properties [4].

We also investigated the data-record-size requirements of minimum-variance-

distortionless-response-type adaptive algorithms to meet a given performance objective in joint space-time signal detection and direction-of-arrival (DoA) estimation problems for direct-sequence spread-spectrum systems. We derived closed form expressions that provide the data record size that is necessary to achieve a given performance confidence level in a neighborhood of the optimal performance point, as well as expressions that identify the performance level that can be reached for a given data record size [7]. This was done by utilizing close approximations of the involved probability density functions. The practical significance of the derived expressions lies in the fact that the expressions are functions of the number of antenna elements and the system spreading gain only, while they are independent of the ideal input covariance matrix which is not known in most realistic applications.

In the presence of additive white Gaussian noise (AWGN), complete elimination of the spread-spectrum interference introduces enhanced noise variance at the decorrelator's output. (Noise variance enhancement at the decorrelator's output refers to the filtered noise variance experienced at the output of a decorrelator that is distortionless in the direction of a given user-signature of interest as it compares to the noise variance at the output of the corresponding MF). It was observed, however, that at times a partial decorrelator (PDEC) can strike an improved balance between interference suppression and noise enhancement when compared to the full decorrelator (DEC) while maintaining a decorrelating structure. That is, instead of decorrelating the complete multiple-access-interference (MAI) in the system, the PDEC chooses purposefully to decorrelate only a part of the MAI so that it exhibits a higher output signal-to-interference-plus-noise-ratio (SINR) than the full DEC. We understand that when unknown interference is present in the system, decorrelating receivers may operate unintentionally under partial decorrelating conditions. We identified necessary and sufficient conditions on the signal energy and signature cross-correlation levels under which the PDEC outperforms the full DEC in the output SINR sense, and we showed why decorrelation of interferers that satisfy such conditions should be purposefully avoided if at all possible [9], [10].

We considered the problem of binary signature set design for DS-CDMA users that transmit over multipath fading channels. First, we considered the problem of selecting optimally the signature of a single user in the presence of spread-spectrum interference (MAI), inter-symbol-interference (ISI) due to the multipath channel, and background noise. The signature is chosen to maximize the output SINR of the ("maximum-SINR") RAKE/MMSE filter. Since optimum binary signature selection has complexity exponential in the processing gain of the system, we proposed [15] a suboptimum computationally efficient algorithm based on the Cholesky decomposition method. The proposed algorithm optimizes the coordinates of the user signature conditionally and is characterized by linear complexity. Finally, we generalized this approach to cover the system-wide multiuser signature set selection problem, where each user's signature is adjusted iteratively according to the above algorithm. The performance of this scheme was evaluated through simulations where we initialized the algorithm at an arbitrary signature set and we observed its convergence to a new signature set for which the output SINR of each user's RAKE/MMSE filter is significantly increased.

Finally, we developed a new multiuser detection algorithm in the context of asynchronous AWGN multiple-access channels [18],[19]. A decorrelating or MMSE/AV multiuser filter is used as a pre-processor that provides initial decisions and reliability measurements based on which an ordered error pattern sequence of tunable length is formed. The error pattern sequence is followed to its end and the most likely bit vector among all visited options is returned. When the length of the pattern sequence is of the order of the number of bits to be detected, the additional imposed computational cost compared to straight decorrelating or MMSE/AV detection is rather insignificant. Still, we saw that this proposed multiuser detection algorithm maintains near-ML bit-error-rate performance over the whole studied SNR range of interest. There is strong

resemblance between this scheme and ``efficient'' decoding algorithms for binary linear block codes [20].

4. PERSONNEL INVOLVED IN EQUIPMENT IMPLEMENTATION

Faculty:
U. Mitra
M. Fitz

5. PUBLICATIONS

1. L. Chu and U. Mitra, "Analysis of MUSIC-based delay estimators for DS/CDMA systems," IEEE Trans. Comm., vol 49, no. 1, pp. 133-138, January 2001
2. L. Chu and U Mitra, "Approximate maximum likelihood sequence detection for ds/cdma systems with tracking errors," IEEE Trans. Comm., vol. 50, no. 2, pp. 344-346, March 2002.
3. M.P. Fitz and U. Mitra, "The 220MHz ITS spectral allocation: Potential, pitfalls and applications," IEEE Communications Magazin, pp.42-54, October 2001
4. U. Mitra and J. Chen, "Optimum Near-Far Resistance for Dual-Rate DX/CDMA Signals: Random Signature Sequence Analysis," IEEE Transactions on Information Theory, to appear December 2003